

The dependence of the bubble density for an ionizing particle on the temperature and pressure in a bubble chamber

Part I. Experimental procedure and results

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With 7 figures in the text

SUMMARY

An account is given of measurements on the bubble density for 18 MeV electrons as a function of the pressure drop and the temperature in a bubble chamber. The investigation has been carried out with propane, Freon-12, and sulphurhexafluoride in the temperature regions (52–68)°C, (68–82)°C, and (10–20)°C respectively. The bubble densities which have been investigated are in the interval (5–30) bubbles/cm. From the results obtained it can be concluded that the operating temperatures of the liquids used lie in the same region when expressed in the reduced temperatures. It is also shown that the bubble density can approximately be represented by a simple formula containing the energy required to create a bubble in the chamber.

Introduction

Although several years have passed since the invention of the bubble chamber [1, 2], only few efforts have been made to investigate systematically the dependence of bubble density on hydrostatic pressure and temperature of the chamber liquid in the moment of exposure [3–6].

Already in the earlier bubble chambers it was observed that the bubble density along the path of an ionizing particle showed a strong dependence on the pressure drop, which can be taken as a measure of the degree of superheat, and on the temperature of the liquid. Attempts were made to correlate bubble densities with expansion ratios and temperature in the chamber [7]. In the cloud chamber the degree of supersaturation is essentially determined by the expansion ratio. In an ordinary bubble chamber, however, the pressure reached during the expansion is—if no pressure stabilizing arrangements are provided—influenced by the speed of the expansion, by boiling at the gaskets and at tiny scratches on the chamber walls, by the cleanness of the liquid, and by the expansion ratio. From this, it is clear that at a given temperature the expansion ratio is not a suitable parameter for characterizing the operating conditions of a bubble chamber. Even in an all-glass chamber it seems difficult to relate superheat and expansion ratio. Instead the temperature and degree of superheat, expressed for instance in terms of pressure, should be chosen as variables

because then the operating conditions can be stated independently of a particular chamber.

At a given velocity and with a fixed charge of the ionizing particle, knowledge of the temperature and the superheat should be sufficient to predict the bubble density. The bubble density is a rapidly varying function of pressure and, therefore, all pressure measurements must be carried out with good accuracy. Pressure oscillations in the chamber liquid normally occur during the expansion cycle and they may under certain circumstances influence the observed sensitivity of the liquid. This implies either that two identical particles with the same velocity passing the chamber in a small time interval may produce tracks showing somewhat different bubble densities, or that the bubble density may vary from one point to another along the tracks.

At first, it does not seem to present any difficulties to determine accurately the temperature of the liquid in an operating bubble chamber. The expansion of the liquid, however, results in a temperature drop of the liquid. Taking into account that the expansion of the liquid is nearly adiabatic but hardly reversible, the temperature determination in practice is accompanied by certain difficulties. Even in the case of an adiabatic and reversible expansion—if one assumes that those properties of the liquid, which are necessary for the calculation of the new temperature, were known for the liquid in the stable, not superheated, state—it would be difficult to find the actual temperature because these properties are not exactly the same in the expanded as in the stable state. However, in practice it should be sufficient to report the temperature existing in the liquid before the expansion and the pressure drop when one wishes to characterize the state of the liquid.

Experimental devices

Bubble chamber

The investigation was performed with a small, cylindrical bubble chamber of stainless steel, the diameter being 50 mm and the photographed volume 80 cm³. The chamber in its original design had no means to control or vary the pressure drop. Therefore, a simple device had to be constructed for this purpose. Fig. 1 shows schematically the chamber and the arrangement for varying the hydrostatic pressure reached during the expansion. The expansion system contains a flexible diaphragm (*A*) which transmits to the liquid the pressure from the compressed nitrogen supplied through a three-way solenoid operated valve (*B*). The energizing of this valve expands the chamber liquid by letting the nitrogen into a container (*C*), the volume of which can be varied. This container has a rather small outlet (*D*). This outlet has only a negligible influence on the pressure in the chamber. Within certain limits the hydrostatic pressure which is reached in the chamber liquid during the expansion is dependent on the volume of the container (*C*).

Dynamical pressure gauge

The arrangement used here to vary the final pressure in the chamber gives at a constant expansion ratio and a constant volume of (*C*) quite reproducible pressure pulses in the liquid. It does not, however, allow a direct determination of the hydrostatic pressure and consequently information about this has to be supplied by other

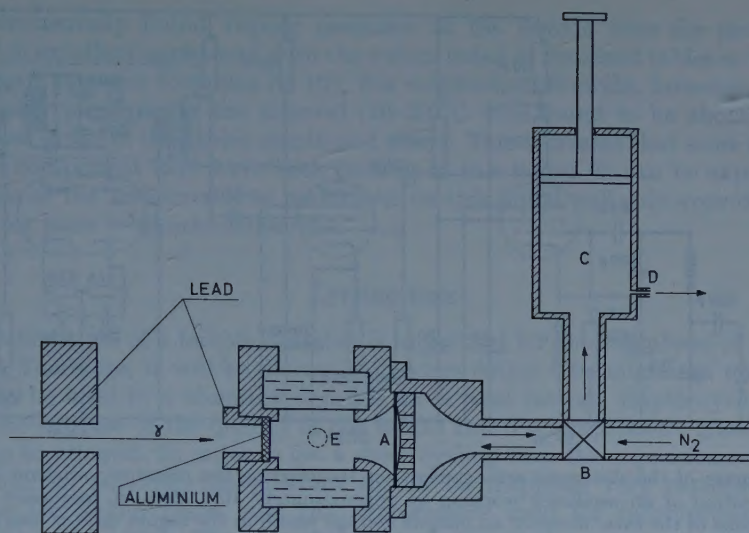


Fig. 1. The bubble chamber and the expansion system shown schematically. The pressure in the chamber during the expansion is controlled with the variable volume (C) as explained in the text. The beam composed of γ -rays and electrons enter the chamber through the Al-window. The pressure transducer (E) is located at the top of chamber.

means. A pressure transducer of the condenser type is inserted in the chamber wall at (E) in Fig. 1 and it is in direct contact with the liquid. A change of the pressure in the liquid changes the capacitance of the pressure transducer, which is one of the frequency determining components of an oscillator. The frequency change of the oscillator is a measure of the pressure change in the chamber. In Fig. 2 the circuit of the oscillator and that of the frequency detector, which is a ratio detector, are shown. The oscillator, working at about 10.7 Mc/s, is of the Clapp type which is characterized by a low frequency drift. The ratio detector is symmetrical and, in the frequency range used, the output voltage is an approximately linear function of the input frequency. Thus, a small unavoidable drift of the oscillator frequency has only a small influence on the pressure differences measured. The pressure transducer in the chamber is connected to the oscillator by means of a coaxial cable, about 1 m in length. The μ A-meter connected across the output serves to help adjust the oscillator frequency, thereby ascertaining that the same region of the output characteristic of the ratio detector is always used. This makes it possible to avoid variations in the sensitivity of the frequency detecting device which may appear as a result of even a small deviation from the linearity of the ratio detector. The output voltage from the ratio detector is fed to a double beam DC oscilloscope, the voltage supply of which is carefully stabilized. The arrangement for hydrostatic pressure determination described here allows accurate calibration with the use of static pressure in the chamber.

Temperature control, photography

The bubble chamber was in good thermal contact with a water bath containing about 8 l. The temperature was stabilized so that the variations in the bath were less

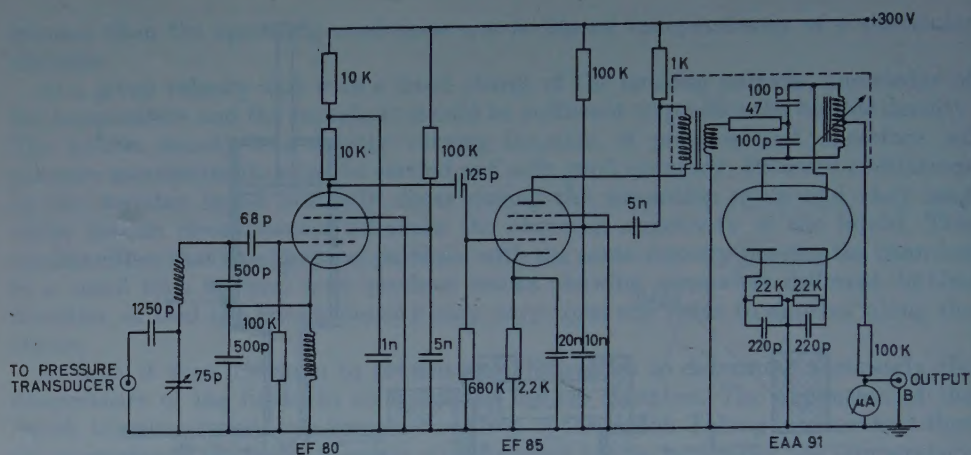


Fig. 2. Diagram of the electronic arrangement for transferring the pressure variation into a frequency variation of an oscillator working at approximately 10.7 Mc/s. A frequency variation gives by means of the ratio detector an output voltage which in the region used is nearly a linear function of the input frequency. The pressure transducer is connected by means of a coaxial cable and the oscilloscope on which pressure measurement are made is connected at the output.

The capacitors and resistors used have low temperature coefficients.

than $\pm 0.1^\circ\text{C}$ and it can be expected that the temperature fluctuations of the chamber liquid, when not expanded, were somewhat smaller because of the time constant for heat conduction through the walls of the chamber.

The light source for photography was an electrical spark in air, as described by Bardócz and Klatzmányi [8] and bright field illumination was used. Photographs of particle tracks in the chamber liquid were taken with a single camera with a magnification of about 0.22.

Liquids used

The bubble chamber with which the investigation has been performed was constructed for liquids working not too far from room temperature. The suitable temperature range for the chamber was approximately $(0-90)^\circ\text{C}$. Therefore, the liquids chosen for this experiment had to be able to work as bubble chamber fluids within the quoted temperature interval. An additional restriction was that the liquids should easily be obtainable with satisfactory purity. The latter property is of importance since the presence of impurities can appreciably change certain properties of the liquid, for instance, the vapour pressure or the surface tension. The use of even slightly impure liquids may give results noticeably different from those which are obtained in pure liquids. Further, the results of the measurements would be reproducible only if the same composition was used at different fillings of the chamber, which might be difficult to achieve when the impurities and the liquid have different vapour pressures.

The liquids used were:

Propane (C_3H_8)	purity $> 99.5\%$
Freon-12 (CCl_2F_2)	purity $\geq 99\%$
Sulphurhexafluoride (SF_6)	purity $> 99\%$

The experimentally found vapour pressures of the liquids were for propane and Freon-12 in excellent agreement with the values listed in standard tables or calculated from vapour pressure formulas [9, 10]. For sulphurhexafluoride, however, the measured vapour pressures in the interval $(10-20)^{\circ}\text{C}$ were found to be about 0.30 atm above those given in the tables mentioned above. This indicates that some amount of a volatile component may have been present in this liquid. It can be expected that the results of the measurements performed on this liquid will only approximatively be valid for pure sulphurhexafluoride.

Cycling time

The cycling time of a bubble chamber is important for the usefulness of the tracks obtained. Therefore, it will be discussed in some detail. The minimum cycling time which can be used in a chamber depends on several factors. Rapid cycling can be used at the expense of the quality of the tracks and if a temperature gradient in the liquid can be allowed. In order to get a short cycling time the expansion ratio should be as small as possible, the pressure should be reapplied very rapidly after the expansion has taken place, and the overpressure used for recompression of the chamber should be high. The rate of supply of nitrogen for compression was, for the chamber here used limited, and thus fast recompression was not possible. The way in which the pressure measurements were performed, which will be described later, implied that a high pre-expansion pressure was unsuitable. A large overpressure would have meant a loss of accuracy in the determination of the hydrostatic pressure because it had then been necessary to reduce the sensitivity of the pressure gauge. So for this reason a relatively long cycling time, 30 sec, was chosen. When so high a pre-expansion pressure was used that the chamber could be expanded every 4th second a change of sensitivity of the liquid in vertical direction could be observed, indicating the presence of a temperature gradient in the chamber. With the use of a 30 sec cycling time, however, no variation of the sensitivity, either in the vertical direction in the chamber or along horizontal tracks, could be observed. This was confirmed by bubble counting on tracks of particles passing at various heights in the chamber. This also indicated that pressure oscillations occurring in the liquid were not large enough to be of any importance.

Experimental details

Determination of hydrostatic pressure

Secondary electrons (and positrons) produced by the γ -beam from a 30 MeV electron-synchrotron were used as ionizing particles. The expansion of the chamber was synchronized with the γ -beam in such a way that the beam passed the chamber when the pressure in the liquid had its minimum value. The pressure pulse which was obtained in the liquid with the expansion system of the type here used had, as a rule, no pronounced plateau at the minimum pressure. Further, variations in the opening time for the solenoid valve were inevitable. Therefore, the pressure in the chamber at the moment the γ -beam arrived had to be measured at every exposure. This was accomplished in the following way. The output from the ratio detector was, as mentioned before, fed to a double beam DC oscilloscope. One beam was used for pressure registration and the other for timing the arrival of the γ -beam. The

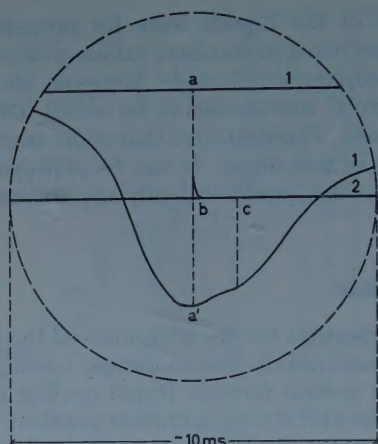


Fig. 3. The oscilloscope screen, where beam number 1 gives the pre-expansion pressure and the pressure pulse during expansion of the chamber. Beam number 2 indicates at *b* the arrival of the γ -beam to the chamber. The pressure is obtained from measurements of the distance *a*–*a'* in the way described in the text. Photography takes place at *c*.

oscilloscope was triggered twice with a time difference of about 50 ms. In the first display, beam no. 1 showed the pressure in the chamber before expansion. This pressure, which was about the same before every expansion for a given temperature, could be measured separately by a manometer. In the second display, beam no. 1 showed the pressure variation in the chamber while beam no. 2 gave the exact position of the γ -beam by means of the output pulse from a scintillation detector, inserted in the beam between the accelerator and the chamber. Fig. 3 illustrates what was seen on the oscilloscope screen.

The screen was photographed and from the recordings on the corresponding film, the pressure of the liquid in the chamber at the moment of exposure could be found in the following manner. The difference *a*–*a'* in Fig. 3 was determined as it was a measure of the total pressure drop in the liquid at the moment when the γ -beam entered the chamber. The pulse at *b* marked the arrival of the γ -beam. By means of a calibration curve for the device for pressure measurements the hydrostatic pressure in the liquid could be found and the superheat could then be calculated in terms of pressure drop by subtracting the hydrostatic pressure from the saturation pressure of the liquid.

Since a determination of the hydrostatic pressure consisted of a combination of several measured quantities, the accuracy in a single pressure determination was not very high. The uncertainty in a single determination was estimated to about ± 0.20 atm, corresponding to 1.5 % of the total measured pressure difference. The largest uncertainty was due to an unavoidable variation in the sensitivity of the DC amplifier of the oscilloscope. This variation contributed to the spread with about ± 0.13 atm. The error in a single pressure determination was not very troublesome because a relatively large number of pictures and thus pressure determinations were required to obtain a sufficient number of tracks to get the desirable accuracy in the bubble density. The large number of pictures was necessary because of the rather small photographed volume of the chamber, which implied that, as a rule, only a few acceptable tracks could be obtained in each picture. In order to avoid systematic errors in the determination of the hydrostatic pressure, owing to the variation in the sensitivity of the DC amplifier of the oscilloscope, the measurements at each temperature were repeated at different times and the mean value of the results was accepted.

Exposure of chamber

Because electrons in the energy region of interest here are subject to large Coulomb scattering in liquids, it would have been desirable to use electrons of such energies that straight tracks had been obtained. Moreover, monoenergetic electrons would, of course, have been more suitable since the bubble density along an electron track is a function of the electron energy as pointed out by Blinov *et al.* [4] and Argan *et al.* [11]. In this investigation electrons of well defined energy were not available but only the entire bremsstrahlung spectrum from the 30 MeV electron-synchrotron. When the accelerator was run at its highest energy the γ -beam had a non-negligible pulse length—of the order of 1 ms—and in addition a rather low intensity. The extension in time of the γ -pulse often resulted in a noticeable difference in bubble densities for tracks in the same picture since the pressure in the chamber had changed somewhat during the time interval in which tracks were produced. Therefore, at this high energy of the γ -rays it was difficult to establish a relation between hydrostatic pressure and bubble density.

When the synchrotron was run at its maximum electron energy of about 25 MeV the pulse length was short enough for the pressure in the chamber not to change noticeably during the time of exposure of the chamber.

In order to suppress the low energy part of the γ -spectrum, which in the chamber gave rise to a disturbing background of short tracks with large scattering and thus unsuitable for bubble density determination, an absorber of aluminium, about 50 cm long, was inserted in the γ -beam between the target of the accelerator and the bubble chamber.

Pre-expansion pressure

For all the three investigated liquids the pressure before expansion, p_i , was chosen 5 atm above the saturation pressure, p_∞ , of the liquid at the corresponding temperature. The reason for choosing the initial pressure, p_i , in such a way was the temperature drop in the liquid, due to the expansion. This temperature drop is a function of several factors, especially the total pressure change, $(p_i - p_f)$, where p_f = the final pressure = p , the hydrostatic pressure obtained by expansion. The use of the same overpressure $(p_i - p_\infty)$ for all measurements gives at least reproducible results. For the liquids here when they are used under the circumstances stated the temperature drop during the expansion should, according to experiments in propane at 60°C [12], be of the order of 0.7°K. However, as we are only interested in the bubble density as a function of pressure drop for given temperatures, it is sufficient to state the conditions under which the measurements have been performed.

In the following, primed letters will denote the temperature of the liquid before expansion, saturation pressure at the same temperature etc., while unprimed letters will denote that the effect of the temperature drop has been taken into account.

Selection of tracks

Only tracks showing relatively low small angle scattering and with a minimum length of about 4 cm were accepted for bubble counting. This restriction was adopted because the bubble density obtained from very short or scattered tracks might be impaired by appreciable errors. As mentioned in the preceding section the bubble

density along the track of an electron is dependent on the electron energy. The increase in bubble density found by Argan *et al.* [11] is of the order of 6% when the energy increases from 5 MeV to 21 MeV. The mean energy of the electrons in this experiment was roughly estimated by small angle scattering measurements and was found to be about 18 MeV. It can be expected that this mean electron energy was nearly the same in all three liquids investigated. A more precise energy determination was hardly possible with the short tracks available (5 cm) and a usable energy determination on individual tracks was quite impossible. The relation between bubble density and electron energy seems to be a rather linear one and, consequently, the error introduced by using the mean value of the electron energies should be negligible. Tracks with lower bubble densities than about 4 bubbles/cm were rejected because it was difficult to follow such tracks in the background which was present. For reasons which will be given in connection with the discussion of the correction for dip of tracks and the coalescence of adjacent bubbles, tracks showing bubble densities higher than about 35 bubbles/cm were also rejected.

Correction for dip etc.

As the tracks in the chamber were photographed with a single camera, the dip angles could not be measured for individual tracks. The effect of dip must be taken into account, otherwise the observed bubble densities will systematically come out too high. A good estimate of the dip can be obtained by a study of the distribution of the angles which the tracks in the chamber form with the direction of the incident γ -beam in the plane at right angle to the optical axis of the camera. The angular distribution in the plane containing the incident beam and the optical axis can be expected to be about the same. In this way it was found that the measured mean bubble densities should be multiplied by the factor 0.98 to correct for dip. A small error in this correction factor will not influence the results noticeably.

A correction much more important for the observed bubble densities is necessary because of the coalescence of adjacent primary bubbles and the limited optical resolution of the photographic system. Without correction for this effect the result will be that the number of primary bubbles will be underestimated and the measurements will to some degree be dependent on the arrangements of a special chamber. The true bubble density sought here must, for instance, be independent of bubble diameters. Assuming that the primary bubbles are distributed according to a Poisson distribution [13] the true bubble density can be found from a study of the distribution of the spacings between the bubbles. The experimental distribution is modified for small spacings.

In an experiment performed with a bubble chamber of the type here used and with a single camera the problem is somewhat more complicated than usual. The rate of growth of a bubble is strongly dependent on temperature and pressure drop in the liquid [14]. Furthermore, temperatures and pressure drops are varied over comparatively large ranges, which makes it necessary to vary the delay considerably before photographing. The bubble diameters can, of course, only be measured after the film has been developed and therefore the delay must be chosen so that the bubbles, as seen directly in the chamber, always appear to be of about the same size. The mean bubble diameter was in this investigation determined to $100\ \mu$ with a spread of about 30%, and the estimated mean correction amounted to about 10% for an uncorrected

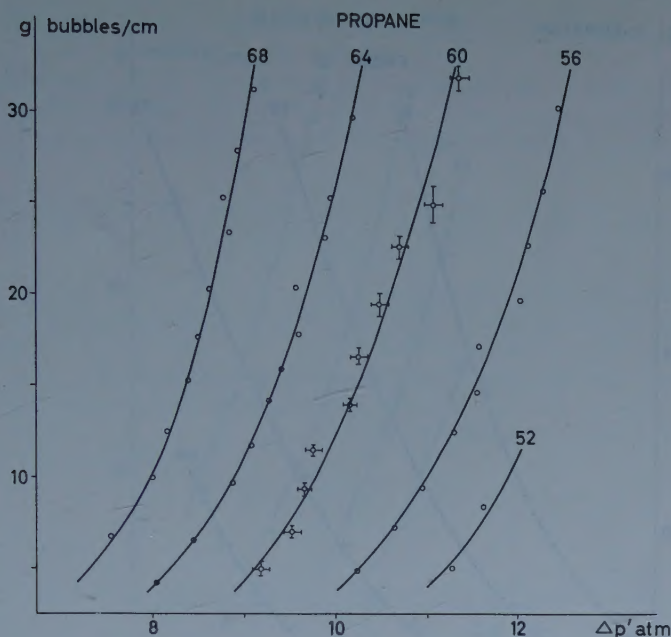


Fig. 4. The bubble density, g , in propane for electrons of 18 MeV mean energy plotted versus the pressure reduction, $\Delta p'$, in the liquid with the temperature (in $^{\circ}\text{C}$) as a parameter. The temperatures given are those existing in the liquid before expansion. The errors are shown for only one temperature since they are nearly equal for all the points measured.

bubble density of 25 bubbles/cm. At much higher bubble densities the correction would have been very difficult to estimate unless the tracks had been stereophotographed and the bubbles had been of the same size.

Experimental results

The bubble density was determined and plotted versus the pressure drop with the temperature as a parameter. The lower temperature limit in the chamber was determined by the circumstance that the chamber at that temperature had to be sensitive enough to record tracks with so many bubbles per unit length that reproducible bubble counting could be performed. Correspondingly, the upper temperature limit was fixed since foam could not be allowed to disturb the counting too much. In propane, for instance, it was found that at 72°C tracks could still be distinguished in the chamber but reliable bubble counting was quite impossible.

In Fig. 4 the measured bubble density in propane is plotted versus the corresponding pressure drop, $\Delta p' = (p'_{\infty} - p)$, with the temperature of the unexpanded liquid as a parameter. The limits of error in the pressure determinations have been calculated taking into account the errors mentioned in connection with the description of the dynamical pressure gauge as well as the total number of measurements. The standard deviation in the determinations of the $\Delta p'$ amounts to about 0.10 atm. The uncertainty in the bubble densities have been estimated regarding, on one hand, the

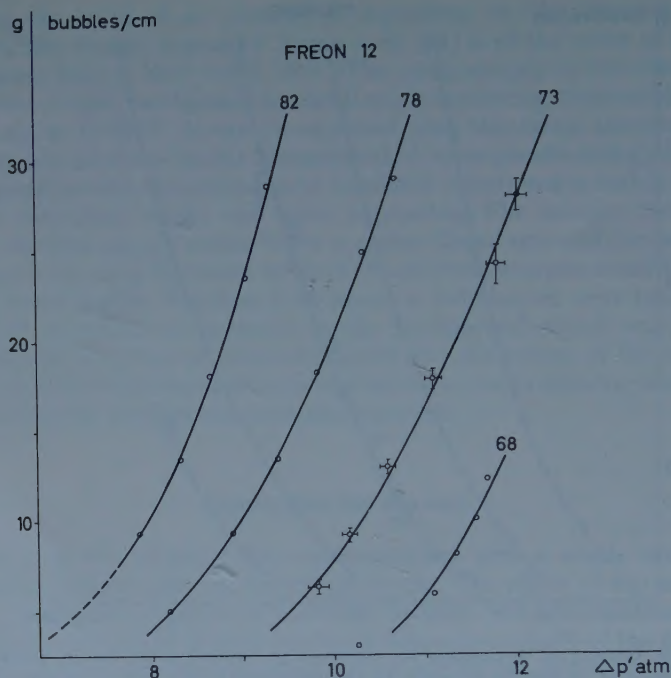


Fig. 5. Bubble density in Freon-12 in the temperature range (68–82)°C.

corrections necessary, especially because of the coalescence of adjacent bubbles which is important mainly at high bubble densities, on the other, the total number of bubbles counted to obtain each point. The mean value of the standard deviations for the bubble densities determined is roughly ± 0.7 bubbles/cm.

Fig. 5 and 6 show the corresponding measurements in Freon-12 and sulphurhexafluoride. The error limits for the measurements on these liquids are about the same as those for propane. The results obtained for sulphurhexafluoride may have been more influenced by the presence of impurities than those for propane and Freon-12. As mentioned before, for sulphurhexafluoride exists a discrepancy between the measured vapour pressures and those calculated according to formulas [9].

Operating temperatures

If the investigated temperature regions for the liquids used here are expressed in terms of the reduced temperatures, T'/T_c , where T' is the actual temperature and T_c the critical temperature of the liquid in absolute temperatures they are nearly the same, which is shown in Table 1. However, it must be pointed out that while the upper temperature limit, T'_u , can be at least approximately fixed independent of the bubble chamber because of the appearance of foam, the lower limit, T'_l , seems to be solely dependent on the pressure reduction employed and can, no doubt, be extended to quite low values when large negative hydrostatic pressures in the liquid are used.

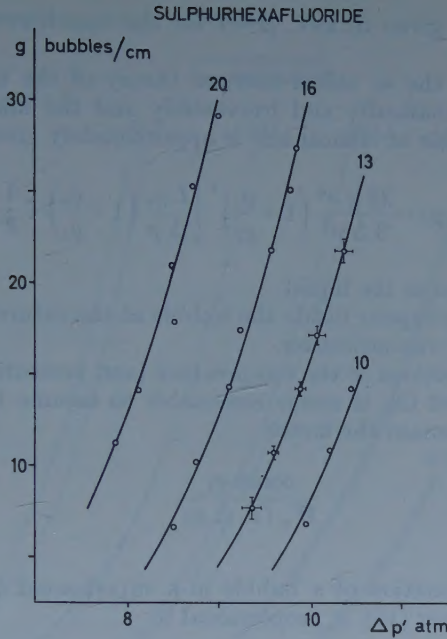


Fig. 6. Bubble density in sulphurhexafluoride in the temperature range (10–20)°C.

Table 1.

Liquid	T_c °K	$\frac{T'_l}{T_c}$	$\frac{T'_l + T'_u}{2 T_c}$	$\frac{T'_u}{T_c}$
Propane	368.8	0.882	0.904	0.925
Freon-12	384.7	0.887	0.905	0.923
Sulphurhexafluoride	318.7	0.889	0.904	0.920

Empirical relation for the bubble density

It would be interesting if a simple formula could be found giving the bubble density as a function of temperature and degree of superheat. If one considers the strong experimental evidence that the bubbles are nucleated by δ -rays from the ionizing particle [4, 13], it can be noted that the number of δ -rays per cm, n_δ , with energies in the interval (W_1, W_2) , for a singly charged particle is given by

$$n_\delta = \frac{153}{\beta^2} q_l \frac{Z}{M} \left[\frac{1}{W_1} - \frac{1}{W_2} \right], \quad (1)$$

where β = velocity of the particle with the velocity of light as unity,
 q_l = density of the liquid (g/cm³),
 Z = number of electrons in a molecule of the liquid,
 M = molecular weight of the liquid.

W_1 and W_2 are to be given in keV. $\beta \approx 1$ for the case here considered (18 MeV electrons).

Further, according to the so called thermal theory of the bubble chamber, the bubbles are formed adiabatically and irreversibly and the minimum energy, W_m , required to create a bubble of critical size is approximately given by [12]

$$W_m = W_m(T, \Delta p) = \frac{32 \pi \sigma^3}{3 \Delta p^2} \left(1 + \frac{\rho_v}{\rho_l}\right)^2 \left[\frac{L \rho_v}{\Delta p} \left(1 + \frac{\rho_v}{\rho_l}\right) + \frac{1}{2} - \frac{3}{2} \frac{T}{\sigma} \frac{d\sigma}{dT} \right], \quad (2)$$

where σ = surface tension of the liquid,

ρ_v = density of the vapour inside the bubble at the saturation pressure,

L = latent heat of vapourization.

σ , ρ_v , ρ_l , and L are functions of the temperature (and pressure).

Therefore, from (1) and (2), it seems reasonable to assume that the formula for bubble density should contain the factor

$$\frac{\text{const } \rho_l}{W_m(T, \Delta p)}, \quad (3)$$

when $W_m = W_1 \ll W_2$.

The probability of formation of a bubble in a superheated liquid, under the assumptions made by Volmer [15], is proportional to

$$\exp(-\text{const } W_r), \quad (4)$$

where W_r = the energy required to form a bubble isothermally and reversibly.

Since the bubble formation in a bubble chamber is assumed to be adiabatic and irreversible instead of isothermal and reversible, which implies $W_m \gg W_r$, the proportionality constant appearing in front of the energy term in (4) may be quite different in the adiabatic case which is of interest here.

So, for these reasons, the following relation was fitted to the experimental values of the bubble density, g ,

$$g = \frac{A \rho_l}{W_m(T, \Delta p) \rho_0} \exp(-\alpha W_m(T, \Delta p) \rho_0 / \rho_l), \quad (5)$$

where A , α , and ρ_0 are constants, ρ_0 is the density of the liquid at an arbitrary temperature, T_0 , chosen in the temperature interval, in which the formula should be used. The factor ρ_0 / ρ_l in the exponent appears, because the energy W_m required to form a bubble of critical radius is not supplied by the liquid but comes from the energy deposited by δ -electrons. The energy given up by such electrons to limited domains in the liquid is assumed to depend on the density of the liquid in the way described in the paper by Johansson [12].

After correction for the temperature drop in the liquid during the expansion (0.7°K), the data recorded in Fig. 4-6 were used to determine the constants A and α in the relation (5). The values found are given in Table 2. In the table the chosen values of the temperatures T_0 , which determine ρ_0 , are also given. The numerical values appearing in the table are valid when the energy W_m is expressed in keV and the bubble density, g , in bubbles/cm.

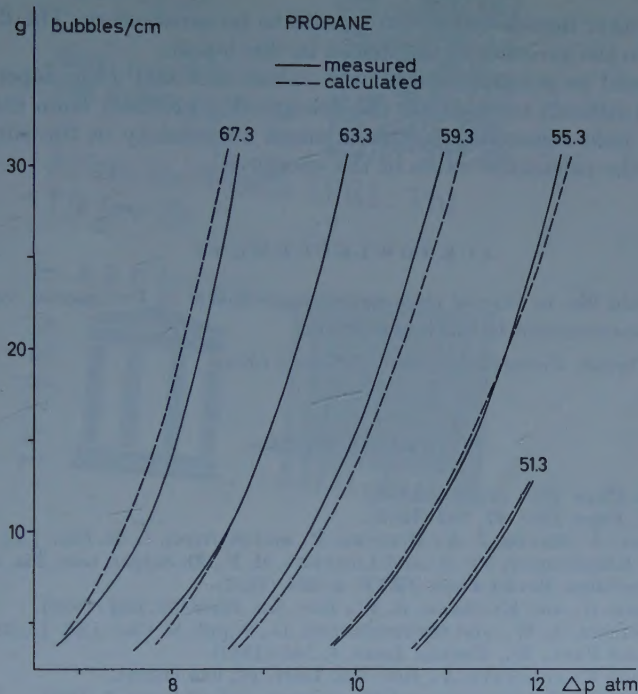


Fig. 7. Experimentally found bubble densities in propane together with those calculated according to the formula given in the text. The temperatures (in °C) of the expanded liquid are given at the curves.

Table 2.

Liquid	T_0		A	α
	°C	°K		
Propane	59.3	332.5	35.1	9.42
Freon-12	72.3	345.5	16.2	9.13
Sulphurhexafluoride	12.3	285.5	44.8	16.4

In Fig. 7 the bubble density for propane is shown as calculated from (2) and (5) with the constants given in Table 2 together with the experimentally obtained results. The agreement seems striking considering that the uncertainty in the pressure determinations is expected to be about 0.10 atm. The maximum difference between calculated and measured pressure drops at any given bubble density is less than 0.2 atm.

For Freon-12 the agreement between experimental and calculated values was somewhat better than that for propane. The difference between measured and calculated pressure drops at any given bubble density was for this liquid always less than 0.1 atm. For sulphurhexafluoride, however, the agreement was not quite so

good as for the other liquids but it can be said to be satisfactory. The deviation can perhaps be due to the presence of impurities in this liquid.

Finally, it should be pointed out that the values of A and α are dependent on the energy W_m . It is difficult to calculate the energy, W_m , precisely from (2) even if this equation should hold rigorously because a small uncertainty in the surface tension strongly affects the calculated value of the energy W_m .

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